Research Note

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
OGDEN UTAH

U.S. Forest Service
Research Note INT-39 1965

CHARACTERISTICS OF BACKFIRES AND HEADFIRES IN A PINE NEEDLE FUEL BED

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ABSTRACT

Burning characteristics of backfires, headfires, and no-wind fires in fuel beds of ponderosa pine needles were compared at the Northern Forest Fire Laboratory. Data gathered under controlled laboratory conditions indicate that fires backed into the wind (backfires) consistently burn slower, longer, and deeper than fires burned with the wind (headfires). In this investigation, increasing air velocity had a marked effect on headfires, but did not significantly change the rate of spread and other burning characteristics of backfires. Field studies are needed to establish more conclusively the differing capabilities of headfires and backfires in preparing seedbeds and planting sites.

Fires in natural forest fuels exhibit different characteristics when backing against the wind or downslope than when heading with the wind or burning upslope. Forest managers using prescribed fire for site preparation and hazard reduction use both headfires and backfires to burn slash after timber harvest operations. They frequently adjust ignition patterns to utilize both the slow-burning features of backfires for hazardous block edges, and the rapid rate of spread of headfires for internal areas.

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Because headfires and backfires spread at different rates, it is reasonable to assume that their other characteristics also vary. For example, the author, while burning for jack pine regeneration in Michigan, observed that backfires usually burned deeper into the duff under jack pine slash than headfires did.[2] However, published reports of comparisons of temperature and duration are not always consistent. One report[3] found that temperatures of backfires were significantly higher than temperatures of headfires up to a height of about 18 inches above burning longleaf pine needle and grass fuels. Both kinds of fire reached a maximum temperature about 5 inches above the ground. Conversely, another study[4] recorded temperatures of headfires 1 foot above the ground in natural gallberry-palmetto fuels that were two to six times greater than backfire temperatures at the same height. Measurements by Fahnestock and Hare[5] on the bark of trees over burning longleaf pine needles showed backfire and headfire temperatures of both types of fire were equal near the ground; but headfires became much hotter 1 foot and more above ground line.

Users of prescribed fire need more definite information about the burning and site-preparation characteristics of both backfires and headfires. Any such comparison should first be made in a carefully controlled environment. For this reason, in 1965, researchers at the Northern Forest Fire Laboratory burned a series of fuel beds of ponderosa pine needles. The study included headfires and backfires burned in a wind tunnel at comparable windspeeds, fuel moistures, and temperatures, and no-wind fires burned in a combustion chamber. This paper compares the data taken from 15 backfires with data collected earlier in the study by Rothermel and Anderson[6] from 25 headfires and from 12 fires burned in the absence of wind.

PROCEDURES

Backfires were burned in uniform fuel beds of ponderosa pine needles 18 inches wide, 8 feet long, and 3 inches deep, using procedures and instrumentation described by Rothermel and Anderson.[7] Free airstream velocities were $1\frac{1}{2}$, 3, 5, and 8 miles per hour. Fuel moisture of the needles was in equilibrium with the environment at the time of burning. Fuel moisture was 8 percent at a dry bulb temperature of 90° F. and a relative humidity of 47 percent. A narrow tray of flaming alcohol at the lee edge of the fuel bed assured uniform ignition.

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[2] Beaufait, W. R. Procedures in prescribed burning for jack pine regeneration. Michigan Col. Mining and Technol. Tech. Bul. 9, 39 pp. 1962.

[3] Lindenmuth, A. W., and G. M. Byram. Headfires are cooler near ground than backfires. U.S. Forest Serv. Fire Control Notes 9(4): 8-9. 1948.

[4] Davis, L. S., and R. E. Martin. Time-temperature relationships of test headfires and backfires. U.S. Forest Serv. Fire Control Notes 22: 20-21. 1961.

[5] Fahnestock, G. R., and R. C. Hare. Heating of tree trunks in surface fires. Jour. Forestry 62: 799-805. 1964.

[6] Rothermel, R. C., and H. E. Anderson. Fire spread characteristics determined in the laboratory. (In preparation.)

[7] Ibid.

Thermocouples located at the surface of the fuel measured the rate of spread and duration of flaming. A strain-gauge weighing system monitored fuel loss throughout each fire. Flame dimensions were photographed as the flame front passed each $\frac{1}{2}$-foot interval along the fuel bed.

Fires were replicated three times at each of the four wind conditions, and one additional bed was burned at each of the three lowest windspeeds.

RESULTS

The most important burning characteristics of the backfires are summarized in table 1. Analysis of variance for each characteristic shows no statistical differences attributable to changes in windspeed. The remarkable uniformity in rate of spread, residence time, flame depth, and weight loss recorded in this study suggests that fires backing into the wind may be expected to behave alike, regardless of air velocity. The only observed difference among backfires was a progressively greater flame angle from the vertical as velocity increases.

Table 1.--Burning characteristics of backfires with different air velocities[1]

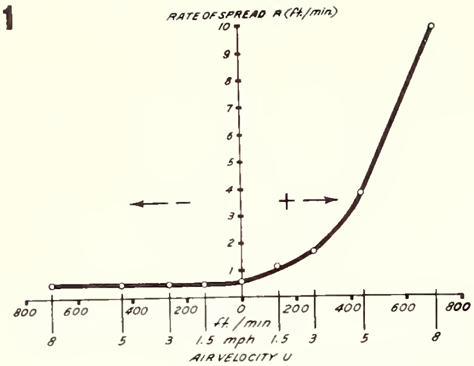
Air velocity m.p.h.	Number of fires	Mean rate of spread	Mean residence time	Mean flame depth	Mean weight loss
		Ft./min.	Min.	Ft.	Lbs./min.
1.5	4	0.50	1.96	0.96	0.40
3	4	.51	2.02	1.05	.39
5	4	.49	2.40	1.14	.39
8	3	.50	2.03	1.02	.36
Calculated "F"[2]		1.14	1.19	0.41	0.62

[1] Rate of spread, residence time, and flame depth were determined by temperature records from 12 thermocouples in each fire. Weight loss was recorded after the fires attained a steady rate of spread.

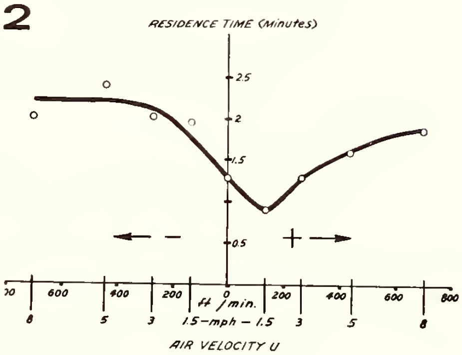
[2] Table "$F_{.05}$" = 3.59 with 3 and 11 degrees of freedom.

Striking contrasts appear when we compare the backfire data with the results obtained previously from headfires and burning in the absence of wind. Figures 1-5 graphically express burning and flame characteristics over a continuous scale of air velocity from minus 8 (backfire) to plus 8 miles per hour (headfire).

1

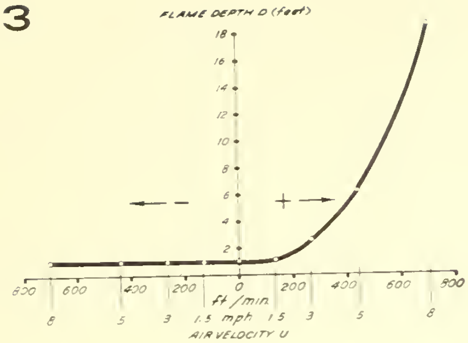


2

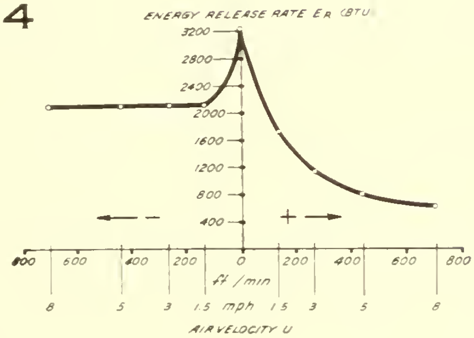


Figures 1-5.--Fire parameters are plotted against air velocity. Values to the left of zero are for backfires; those to the right of zero are for headfires.

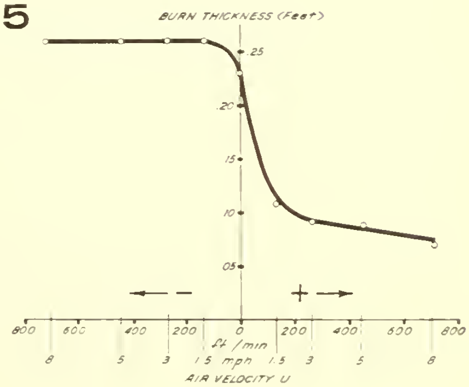
3


FLAME DEPTH D (feet)
18
16
14
12
10
8
6
4
2
800 600 400 200 0 200 400 600 800
ft /min
8 5 3 1.5 mph 1.5 3 5 8
AIR VELOCITY U

4


ENERGY RELEASE RATE E_R (BTU
3200
2800
2400
2000
1600
1200
800
400
800 600 400 200 0 200 400 600 800
ft /min
8 5 3 1.5 mph 1.5 3 5 8
AIR VELOCITY U

5


BURN THICKNESS (Feet)
.25
.20
.15
.10
.05
800 600 400 200 0 200 400 600 800
ft /min
8 5 3 1.5 mph 1.5 3 5 8
AIR VELOCITY U

Rate of spread.--This characteristic is low in backfires and no-wind fires, but high in headfires. Rate of spread for headfires is an exponential function of positive air velocity. It is probably influenced by radiant preheating from flames leaning over unburned needle fuels. As air velocity increases, flames of a headfire lean progressively closer to unburned fuels, and at the same time lengthen to cover 1 to 4 feet of the fuel bed ahead of the moving front. Under no-wind conditions, the flame is generally perpendicular to the fuel bed, and radiant preheating is greatly reduced. Flames at the leading edge of a backfire actually lean away from unburned fuels.

Since a flame front radiates as the cosine function of the angle from its surface, flames of backfires and no-wind fires do not preheat unburned fuels as headfires do. Indeed, the flow of air over unburned fuels probably cools the leading edge of backfires. The consistent rate of spread of backfires, regardless of air velocity, strongly suggests that flame propagation results from preheating and ignition mechanisms at work beneath the surface of the fuel bed.

Residence time.--Residence time of the fires, or the duration of flaming at a given point on the fuel bed, varies with the change from negative to positive air velocity (fig. 2). The residence time of backfires is not greatly affected by air velocity. Backfires spread more slowly than headfires, they burn longer in place, and, in this instance, they completely consumed the fuel beds. Residence time is difficult to measure when, as in the case of no-wind fires and headfires, fuels are not completely consumed by the fire (see Burn thickness below). For this reason, variation in residence time between no-wind fires and headfires cannot be satisfactorily explained.

Flame depth.--Since rate of spread and residence time are uniform for backfires, it follows that flame depth, or dimension of the flame parallel to its direction of movement, does not vary with air velocity. However, flame depth of headfires increases at an exponential rate. Figure 3 shows this relation, with backfire flames consistently 1 foot in depth.

Unit energy release rate.--We have seen that backfires are slower moving, of longer duration, and have less flame depth than headfires. The next step is to identify differences in burning rate. From data on weight loss it is possible to calculate the steady rate at which combustion releases the energy stored in the fuel. Figure 4 gives the results of calculations for each air velocity. Unit energy release rate drops faster in headfires than in backfires from a peak of 3,200 B.t.u./square foot minute under a no-wind condition.

Unit energy release rate is greatest when low rates of spread combine with brief residence times. As air velocity increases, headfires spread faster, but consume only surface fuels. As shown previously, residence time is briefer when the fire backs into the wind. Backfiring and long residence time reduce unit energy release rate. Had our fuel beds been thicker than 3 inches, the backfires might have maintained a greater energy release rate than they did. This view is supported by data on burn thickness (fig. 5).

Burn thickness.--We calculated the amount of fuel consumed per unit area by combining weight loss and rate of spread data. Since the area of the fuel bed was known, these values were readily converted to a measure of how deeply the fire burned into the fuel bed. The resulting estimates of burn thickness are more precise than physical measurements of the depth of fuel remaining after the fire. Headfires consume less fuel as positive air velocity increases (fig. 5), whereas backfires consume more fuel at a steady rate once negative air velocity exceeds 1.5 m.p.h. In this study, backfires burned at least twice as deep into the fuel bed as headfires did. Backfires consumed all of the fuel available and drove moisture from the asbestos base of the frame. It therefore seems reasonable to assume that the backfires would have burned even more fuel from a deeper bed, and thus would have increased the energy release rate. The no-wind fire left some residual fuel. Headfires left more fuel unburned than they consumed.

SUMMARY AND CONCLUSIONS

Burning characteristics of backfires in beds of ponderosa pine needles 3 inches deep and 18 inches wide did not change over a range of $1\frac{1}{2}$ to 8 m.p.h. air velocity. In contrast to headfires, backfires spread more slowly and had less flame depth, longer residence time, and a higher rate of unit energy release. Backfires burned much deeper into fuel beds than headfires did.

The influence of depth and width of fuel beds on characteristics of burning needs further study. The extent to which backfires can burn deep into the needle fuels was not established in this investigation, since fuel in the 3-inch beds was entirely consumed. Experimental needle beds should be deepened until backfires can no longer completely consume the fuel. Other kinds of fuels might exhibit different backfire and headfire relations.

Backfires may facilitate preparation of seedbeds and planting sites by reducing more needle litter on prescribed burning blocks than headfires do. Field tests are necessary to compare the depths of burn and rates of spread of the two types of fire in slash fuels.

DPSU/66/930-3

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